Quasielastic π--nucleus scattering at 950MeV/c

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学位の種類	博　士（理　学）
学位記番号	理博第1584号
学位授与年月日	平成10年3月25日
学位授与の要件	学位規則第4条第1項該当
研究科，専攻	東北大学大学院理学研究科（博士課程）物理学専攻
学位論文題目	Quasielastic π^--nucleus scattering at 950MeV/c (950MeV/cにおける準弾性π^--原子核散乱)
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論 文 内 容 要 旨

Quasielastic scattering is a process that an incident particle elastically interacts with only one nucleon inside a nucleus, all the other nucleons being spectators. The inclusive doubly differential cross section of the quasielastic scattering, as a function of energy loss (the difference between initial and final laboratory kinetic energies of an incident particle), has two characteristic features: one is that the position of the peak corresponds to that of elastic scattering by a free nucleon, the other is that the width of the peak reflects internal motion of individual nucleons in a target nucleus. Because a nucleon has spin and isospin of 1/2, there are six couplings of external fields to a free nucleon, isoscalar/isovector (T=0/T=1), and spin 0/spin 1, with spin 1 having components of transverse and longitudinal with respect to the momentum transfer vector. The effects of nuclear correlations for the corresponding probes can be observed as changes in cross section, and spectral shape changes due to attractive or repulsive interactions. Thus we can study the nuclear correlations for each spin/isospin channel using the quasielastic scattering. The quasielastic scattering has been studied by using various reactions: (e, e'), (p, p'), (p, n), (^{3}He,t), (π, π'), ($\pi^\pm$, π^0), and (K,K'), because each probe has its own characteristic excitation mode.

The present experiment is a study of quasielastic π^--nucleus scattering at 950 MeV/c. The aim of the work is to study the nuclear response through a scalar-isoscalar dominant probe. An advantage of the present experiment compared to the previous one at 624 MeV/c is the predominance of the scalar-isoscalar channel. Fraction of the scalar-isoscalar channel in a total strength is more than 70% for a momentum transfer, q , ranging from 350 to 550 MeV/c. The higher beam momentum of 950 MeV/c makes pions a better probe of the nuclear response in the scalar-isoscalar channel. Further, the previous data may be affected by a large distortion at high q, because the outgoing pion energy is in the delta resonance region. A higher beam energy is preferable to be relatively free from final state interaction.

The experiment was performed at the KEK 12-GeV proton synchrotron using the K6 beam line and the Superconducting Kaon Spectrometer (SKS). The doubly differential cross sections were measured for a wide range of q from 350 to 650 MeV/c, and six nuclei, D, ^{6}Li, C, Ca, Zr, and ^{208}Pb were used to study mass-number A dependence of the quasielastic

scattering.

The measured spectra clearly show the characteristic shape of a quasielastic peak, centered at the energy loss corresponding to that of free π^--nucleon elastic scattering and broadened due to the internal motion of individual nucleons inside a nucleus.

First, quasielastic cross sections, peak widths, and peak centroids' are extracted and discussed based on a non-interacting Fermi gas model and an eikonal approximation. The Fermi gas model well describes the extracted cross sections, and an effective number of nucleons A_{eff} is obtained. The A dependence of A_{eff} follows a power law, $A_{eff} \propto A^{\alpha}$. The present value for the exponent $\alpha = 0.42 \pm 0.01$ indicates that pions are largely absorbed at the nuclear surface and thus scattered only from the surface region of a nucleus. A calculation based on the eikonal approximation well reproduces the A dependence. The Fermi momenta k_F are obtained from the extracted peak widths using the Fermi gas model. There is a sharp rise in k_F with mass number increasing from D to C and moderate increase from Ca to ^{208}Pb, as nuclear density in heavier nuclei becomes saturated.

Secondly, the present results are compared with the kaon data and previous pion data. The present data are quite similar to the kaon data. No pronounced differences are seen except for the region with high energy loss, which will be due to contribution from delta excitation. The comparison with previous pion data shows that the present data are enhanced at the low energy loss side of the peak. This can be interpreted as an increased contribution of the scalar-isoscalar response.

Finally, the ^{12}C data are compared with a theoretical calculation based on a finite nucleus continuum RPA framework using a density-dependent particle-hole interaction. At low momentum transfer, it is clearly seen that the scalar-isoscalar channel dominates the total response. Moreover, at the low energy loss side of the quasielastic peak, the RPA response overestimates the experimental result. This will imply that the interaction used in the calculation is too attractive in the scalar-isoscalar channel. The RPA responses show a hardening with an increase in q. At $q < 550$ MeV/c, total response is dominated by the scalar-isoscalar channel and the peak shift is responsible for a q dependence of the scalar-isoscalar response. At $q > 550$ MeV/c, the hardening of the total response is due to an increasing contribution from non-scalar-isoscalar responses. The q dependence of the observed peak shift on ^{12}C is qualitatively reproduced by the RPA calculation. Thus, the observed peak shift is possibly due to the change of nuclear responses, reflecting the q dependence of the particle-hole interactions.

In conclusion, the present study has revealed the momentum transfer dependence of the scalar-isoscalar response over a wide range of momentum transfer, from 350 to 550 MeV/c, through the pion quasielastic scattering.

論文審査の結果の要旨

原子核反応において，入射粒子と原子核内の核子が，自由空間での入射粒子と核子の弾性散乱として近似できるような散乱をただ一回する場合を，準弾性散乱という。入射エネルギーが十分高く，入射粒子のドブローイ長が核内核子間距離より十分短いような原子核散乱過程においては，準弾性散乱過程の寄与が大きくなる。

本論文は，950MeV/c のパイ中間子-原子核散乱の二重微分断面積測定を陽子，重陽子から鉛に至るまでの広い質量数の原子核に対して，350-650MeV/c までの運動量移行範囲で行ない，原子核の応答関数のうちスカラー・アイソスカラー部分を明らかにしたものである。1GeV/c 運動量領域での準弾性散乱は，これまで行われてきた電子や陽子による準弾性散乱実験や低エネルギー領域のパイ中間子実験に比べ，スカラー・アイソスカラー応答からの寄与が格段に大きく，上記の研究には最も適している。これまで，このように高いエネルギーのパイ中間子ビームによる精度の高い散乱実験は困難であったが，高エネルギー加速器研究機構12GeV陽子シンクロトロンに設置された大型超伝導スペクトロメータを用いて本実験が初めて実現した。測定されたスペクトルから導かれた有効核子数とフェルミ運動量のターゲット原子核質量数に対する依存性等の大局的性質は，アイコナール近似に基ずくモデル計算等でよく再現されることが示された。また，^{6}Li，^{12}Cターゲット核について，準弾性散乱断面積のピーク位置が移行運動量に依存する事も明らかにされ，低エネルギーでの準弾性散乱断面積との比較からスカラー・アイソスカラー応答の移行運動量による違いが原因であることを示した。さらに，本実験スペクトルを最近行われた乱雑位相近似に基づく理論計算と比較し，とくに低運動量移行領域（350－450MeV/c）において，この計算が準弾性散乱ピークの低エネルギー励起側での断面積を過大に評価していることを示した。その結果，広く用いられている粒子空孔有効相互作用のスカラー・アイソスカラーチャンネルにおける引力が大きすぎることを明らかにした。一方，準弾性散乱ピークが，運動量移行が大きくなるにつれ高エネルギー励起側にずれることも観測し，その原因は，主に運動量移行が大きくなるにともない，スカラー・アイソスカラー応答の寄与が減少することによることを示した。

以上本研究は，1GeV/c 領域におけるパイ中間子-原子核準弾性散乱に関する最も質の高い実験をおこない，原子核に対するスカラー・アイソスカラー応答を明らかにしたものである。本論文は，準弾性散乱過程に基づく原子核の応答に関する研究の発展に大きく寄与したものと認められる。したがって，藤井優提出の論文は，博士（理学）の学位論文に値するものであり合格と認める。